USBM Grant No. G133023

THRU-THE-EARTH ELECTROMAGNETICS WORKSHOP

Richard G. Geyer

USBM CONTRACT FINAL REPORT
(Contract/Grant No. G133023)

Date: December 31, 1973

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
WASHINGTON, D. C.

DISCLAIMER NOTICE

PROCEEDINGS OF

THRU-THE-EARTH ELECTROMAGNETICS WORKSHOP

August 15 - 17, 1973

Colorado School of Mines

Sponsored By

United States Bureau of Mines

Edited By Richard G. Geyer

FOREWORD

This report was prepared by Richard G. Geyer under USBM Contract/Grant No. G133023. The grant was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. Howard E. Parkinson acting as the technical project officer. Mr. A. L. Metheney was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this grant during the period April 1, 1973 to December 31, 1973. This report was submitted by the author on December 31, 1973.

Conference Chairman:

Richard G. Geyer	Research Associate, Geophysics Department, Colorado School of Mines

Advisory Committee:

James R. Wait	Director, Environmental Research Laboratories, NOAA; Consultant, Institute of Telecommunication Sciences
Howard E. Parkinson	Supervisory Electrical Research Engineer, Industrial Hazards and Safety Research Center, U. S. Bureau of Mines
James Powell	Staff Research Engineer, Mining Research Center, U. S. Bureau of Mines

Session Chairmen:

Richard G. Geyer	Research Associate, Geophysics Department, Colorado School of Mines
James Powell	Staff Research Engineer, Mining Research Center, U. S. Bureau of Mines
David A. Hill	Research Scientist, Institute of Telecommunication Sciences, Boulder, Colorado
John Murphy	Supervisory Electrical Research Engineer, Industrial Hazards and Safety Research Center, U. S. Bureau of Mines
James R. Wait	Director, Environmental Research Laboratories, Boulder, Colorado

Group Chairmen:

Electromagnetic Noise Environment	John W. Adams, National Bureau of Standards
Location and Direction-Finding	Arnie J. Farstad, Westinghouse Georesearch Laboratory
Uplink and Downlink Communications	Robert L. Lagace, Arthur D. Little, Inc.
Operational Communications	Martyn F. Roetter, Arthur D. Little, Inc.

TABLE OF CONTENTS

Page

PREFACE

Over the past several years the United States Bureau of Mines has supported various research programs oriented toward the development of basic data applicable to the design of electromagnetic communications systems. Such systems would provide rescue communication links during emergencies. They might also serve as monitors of the mine environment, as well as special communication links for increasing the day-to-day efficiency of the mine operations.

Therefore research programs have been involved with experimental and theoretical investigations of wireless signal transmission through the earth. Experimental studies revolve about the identification of the electrical properties of rocks over coal mines insofar as the propagation of communications signals would depend on such properties, on the ambient electromagnetic noise fields over and in coal mines insofar as such noise would limit the detectability of communications signals, and on the effect of mine structures on the transmission of communications signals. Active theoretical work has consisted of the analysis of a variety of techniques for thru-the-earth communications and of a number of approaches for location of trapped miners. To name but a few techniques, either loops or grounded wire may be used for the subsurface or surface antenna. Each may be oriented in a variety of ways. Each may be excited with an impulsive signal or a continuous-wave signal.

In short, a need arose to assemble individuals who have been active in current research on the topic so that the problem of how information may be conveyed by electromagnetic waves propagating through rock media without the benefit of lines and cables may be better understood. Furthermore, some of the limitations and scope of such schemes needed to be identified.

Thus a "Thru-the-Earth Electromagnetics Workshop" was sponsored by the United States Bureau of Mines. This workshop was held at Colorado School of Mines on August 15-17, 1973. The papers which follow are representative of the topics discussed at that workshop.

Richard G. Geyer

Richard G. Geyer, General Workshop Chairman

OBJECTIVES AND CONSTRAINTS OF THROUGH-THE-EARTH ELECTROMAGNETIC COMMUNICATION SYSTEMS

by

Howard E. Parkinson[1]

ABSTRACT

In 1969, new coal mine health and safety legislation was enacted in the United States. As a result of this legislation, the Department of Interior, Bureau of Mines has carried out communications research aimed at developing whole mine communications for increased safety and efficient operation. The research has advanced and many promising results are now being demonstrated to the mining industry. However, there remains a challenge to further improve wireless communications within the mine workings, and through the overburden above the workings. The objectives for future research and development will be discussed, together with the physical and operational constraints that new mine communication systems must face.

INTRODUCTION

The involvement of the U.S. Bureau of Mines, Department of the Interior, with electromagnetic (EM) communications dates back fifty years. Recently, as a result of legislation enacted by the Federal Government in 1969 concerning Coal Mine Health and Safety, the Bureau has entered into a new and promising era of communications research. As part of this effort, the Bureau is endeavoring to exploit the promise of through-the-earth communication by means of EM fields.

The program of the Bureau of Mines is unique. This program is a cooperative effort under the direction of the Bureau. Through contracts and grants, the Bureau purchases the technical efforts of universities, private communications companies – both manufacturers and consultants – and other governmental agencies, and coordinates the participants into a team. Through cooperative cost-sharing agreements with mine operators, research is performed in the working mines, where extensive demonstrations are made of new concepts under actual operating conditions in the mine.

The Bureau's philosophy is to develop day-to-day-operational communications systems that can adequately meet communications requirements for making mining safer on a

---

1. Supervisory Electrical Research Engineer, Industrial Hazards and Communications, Pittsburgh Mining and Safety Research Center, U.S. Bureau of Mines.

day-to-day basis, improving the efficiency of mining operations, and remaining fully operational and ready to provide essential communication needs in an emergency.

THE OBJECTIVES OF MINE COMMUNICATIONS SYSTEMS

Fundamentally, the Bureau has three objectives for communications systems:

(1) To be a silent partner monitoring the mines, watching over the environment to ensure that the mine is providing a healthy and safe working environment;

(2) To provide reliable rescue communication links during emergencies; and

(3) To ensure efficient day-to-day mine operations.

The communications systems designed to achieve these objectives must satisfy the following requirements:

(1) The silent partner monitoring the mine environment must be highly reliable, and is required to work even when there is a loss of power and a loss of wire channels to transmit signals;

(2) The rescue communications system must be able to function under the most adverse conditions, and be able to:

- Allow live miners to notify the surface of their presence in the mine;
- Supply sufficient data to determine the position of the live miners;
- Provide communication with the live miners to assist in their rescue.

(3) The day-to-day operational communication system must be able to report automatically the status of major factors of production; additionally, communication must be extended from fixed locations and vehicles to roving miners, so that a miner working on the face can trouble-shoot equipment directly with his surface supervisor without having to leave the immediate work site at the face.

CONSTRAINTS OF THE MINE ENVIRONMENT

The environment for communications systems in a mine is a severe one, both under normal operating conditions and in emergency situations. This environment, which includes the miner himself as well as his surroundings, poses several major constraints and/or specifications to which the communications equipment must conform.

General Environmental Characteristics

(1) Through-the-earth EM communications systems must operate in the face of the conductivity and depth of the earth overburden. We have chosen values of 10^{-2} mhos per meter and 1,000 feet, respectively, as nominal design values for these parameters. The vast majority of U.S. mines fall within these limits. While higher values do exist, these are difficult to cope with while remaining within reasonable limitations of power, weight, and size for the communications equipment.

(2) The effectiveness of communication is a function of the signal-to-noise ratio. Although we have not accurately determined what the limits on usable signal-to-noise ratio can be, these limits bind us in both the operational and emergency modes. During normal operations, the most adverse noise that we have experienced to date in a mine has been in an all DC mine using 600 volt haulage and face equipment. During emergencies, through-the-earth emergency communications must be received in the face of ambient surface noise of both man-made and natural origin. Examples of performance estimates based on early noise data are shown in Figures 1-3.

Emergency Environmental Characteristics

(3) During a mine disaster tremendous flame pressure fronts are often experienced. The communications gear must be rugged enough to remain workable despite the stresses to which it is subjected. For example, the Bureau has developed special equipment that has endured pressures in excess of 25 psi at temperatures of greater than 1,800°F for 30 seconds.

(4) During an emergency the mine must be assumed to be gassy, and this imposes severe intrinsic safety restrictions[2] on the communications equipment. There are three major restrictions to consider:

(a) The minimum ignition current for a particular value of capacitance in the output of the communications gear;

(b) The minimum ignition current for a particular value of inductance in the communications gear;

(c) The minimum ignition current at the voltage being impressed on the circuit at a particular instant.

---

2. R.J. Redding, "Intrinsic Safety,The Safe Use of Electronics in Hazardous Locations, McGraw-Hill, London, 1971.

Characteristics of a Miner

(5) As a source of power for the communications equipment we have placed strong emphasis on the miner's cap lamp battery, and what we call the surplus energy, the energy available after an 8-hour shift, as shown in Figure 4. The cap lamp consumes 1-1.2 amperes, and the cap lamp cord is designed for this low current. Excessive loss would occur if we were to draw five to six times that current, as might be required by some types of emergency EM transmitter. Critical design constraints are therefore placed on the selection of components used in EM transmitters, and receivers, as well as circuit configurations, to enable the maximum magnetic moment to be developed in the most efficient manner for the desired period of operation.

(6) All equipment must be practical for day-to-day operational use. This will ensure that the miners know how to operate the equipment, and that the equipment is in working order should an emergency develop.

(7) The weight limitations chart (Figure 5) shows the weight of the items now carried by miners. We wish to limit the communications gear carried by the miner to no more than a 5% increase in the weight of the items that he now carries. The section foreman in particular is a key individual in this respect.

(8) The cost of the communications gear must, of course, remain within reasonable limits. The cost chart (Figure 6) shows the selling prices of various equipment often carried by miners. We have estimated what we think should be the cost of simple special communications gear; namely, about $65 for a CW transmitter for locating trapped miners, and about $130 for a call alert/emergency voice receiver such as that shown in Figure 7.

CONCLUDING REMARKS

We have had remarkable success with many of our communications experiments; however, our approaches still need to be refined. You will be hearing about many of these experiments, both with regard to EM propagation and EM noise measurements. This is a workshop seminar. Its output is anticipated to be at least two position papers that will summarize the present state of the Bureau of Mines through-the-earth wireless communications program and progress as you see it, and then define a short- and long-term research effort that you as researchers and equipment developers can participate in to improve these wireless communications capabilities. This definition of research efforts should include estimates of what the dollar cost might be as well as the time necessary to complete each of the suggested projects.

We are indeed grateful for the efforts of each participant and we sincerely hope this seminar will be beneficial to you, as well as to us. We hope that you will go away with a clearer vision of our needs, and that the Bureau, through your eyes, will see more clearly what next steps should be taken in our continuing efforts to improve mine health and safety.

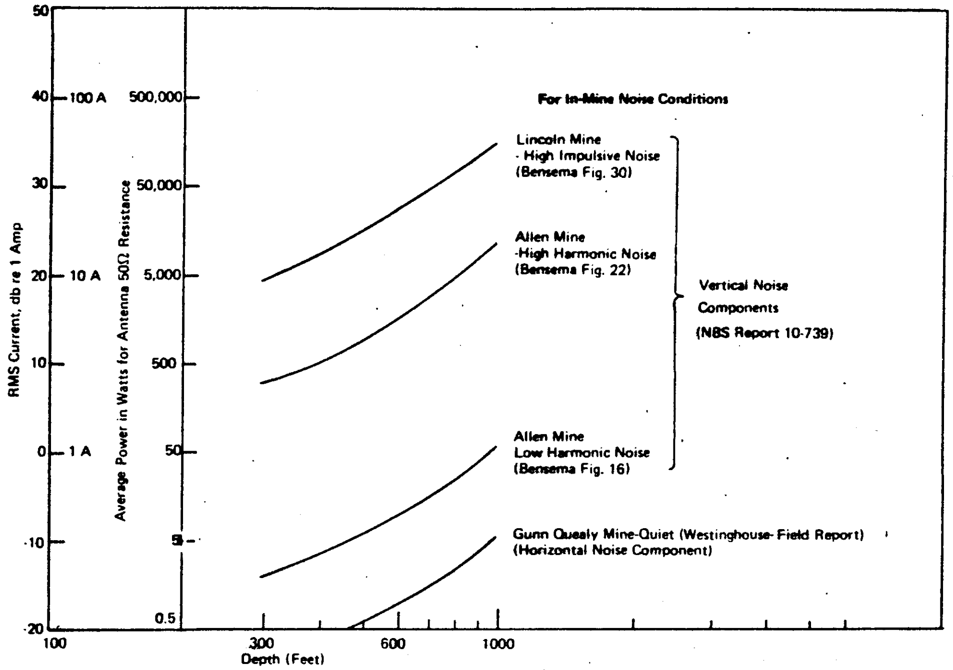

FIGURE 1 DOWNLINK AVERAGE POWER AND RMS ANTENNA CURRENT FOR 12db S/N RATIO OVER THE VOICE BAND 500 - 3000 Hz for $\sigma = 10^{-2}$ mhos/meter and Long Wire Transmit Antenna

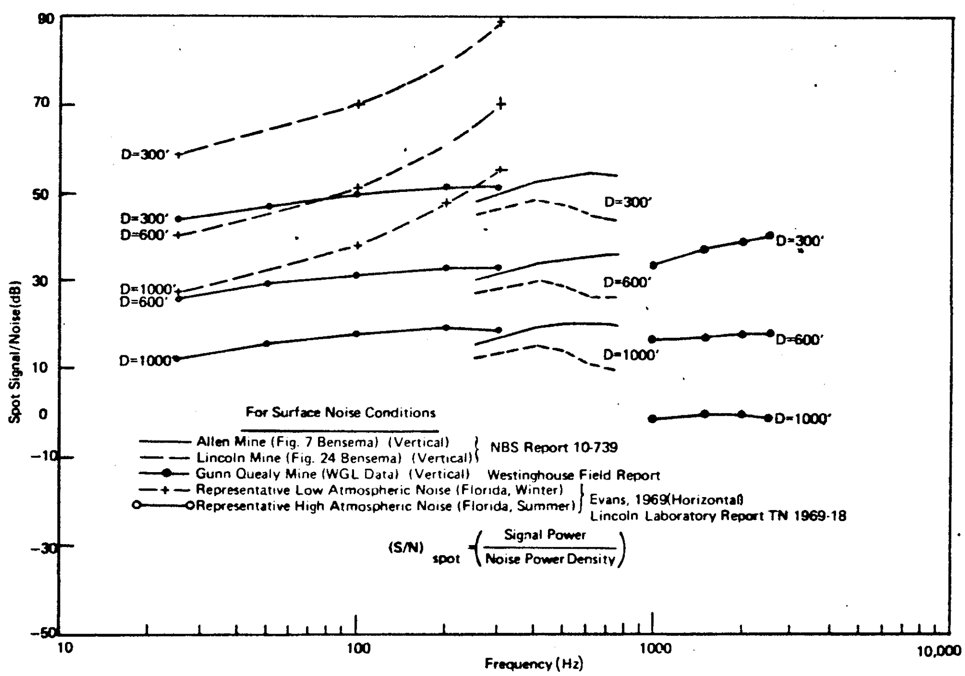

FIGURE 2 UPLINK SIGNAL-TO-NOISE RATIO FOR LOOP TRANSMIT ANTENNA, OVERBURDEN CONDUCTIVITY $\sigma = 10^{-2}$ mho/meter, LOOP MOMENT NAI = 1460 Amp-meter^2

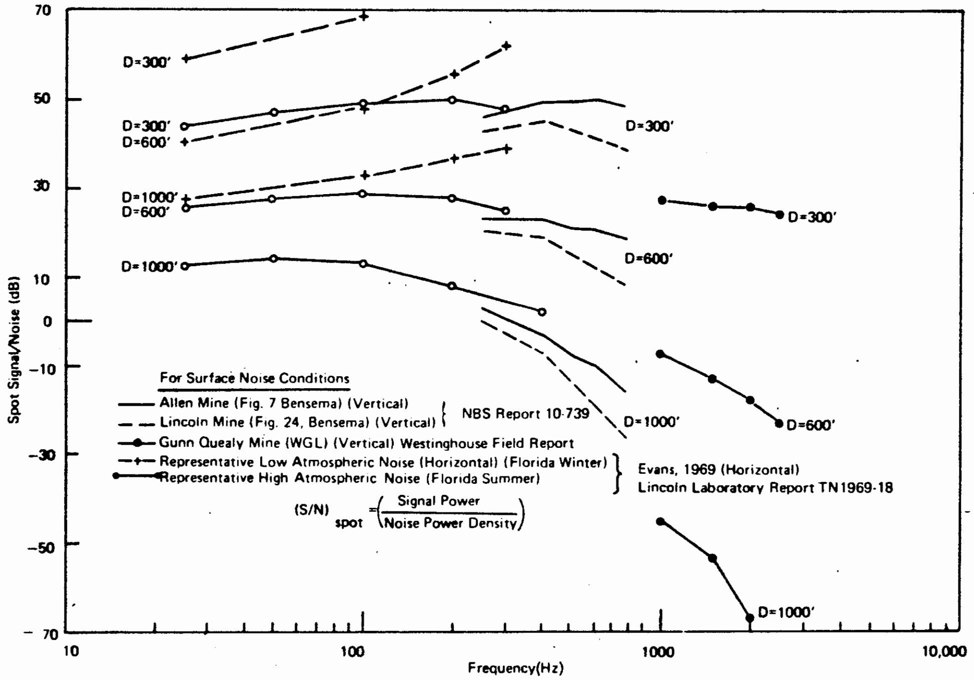

FIGURE 3 UPLINK SIGNAL-TO-NOISE RATIO FOR LOOP TRANSMIT ANTENNA, OVERBURDEN CONDUCTIVITY $\sigma = 10^{-1}$ mho/meter, LOOP MOMENT NAI = 1460 Amp-meter^2

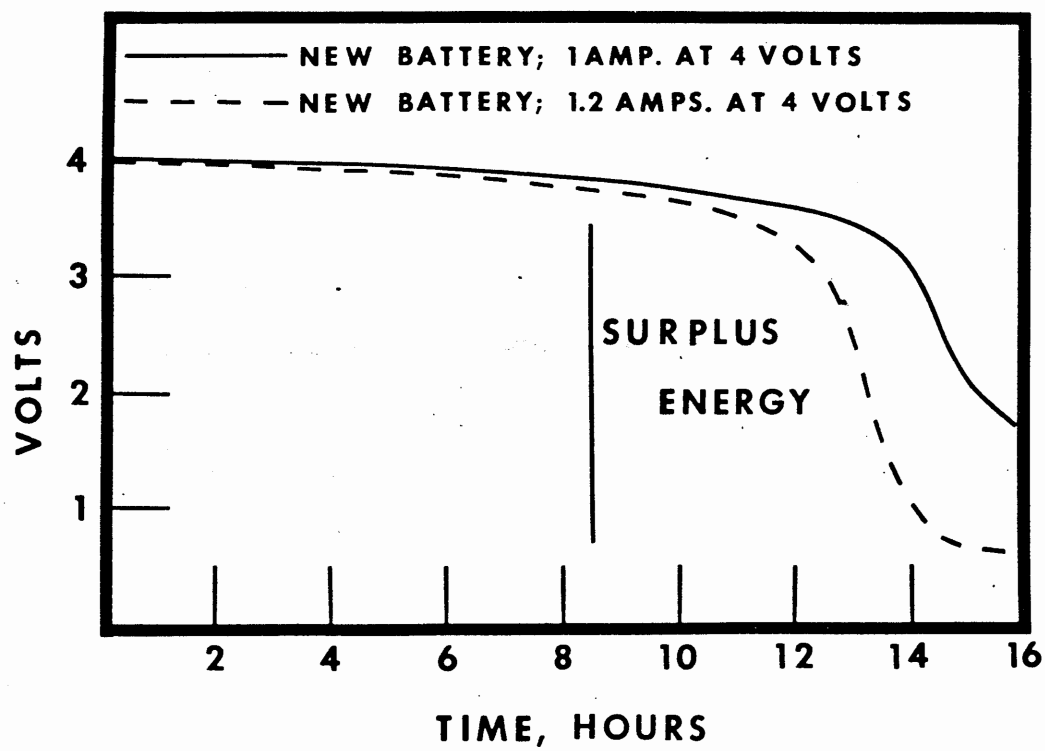

Figure 4 Voltage Curves for Miner's Cap Lamp Battery

Figure 5
TYPICAL EQUIPMENT WEIGHTS

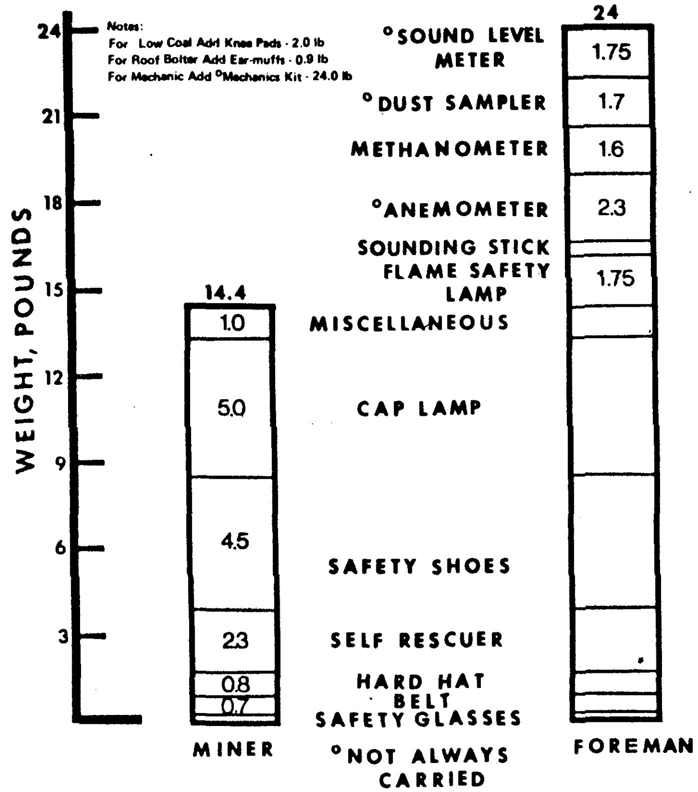

Figure 6 TYPICAL EQUIPMENT COST

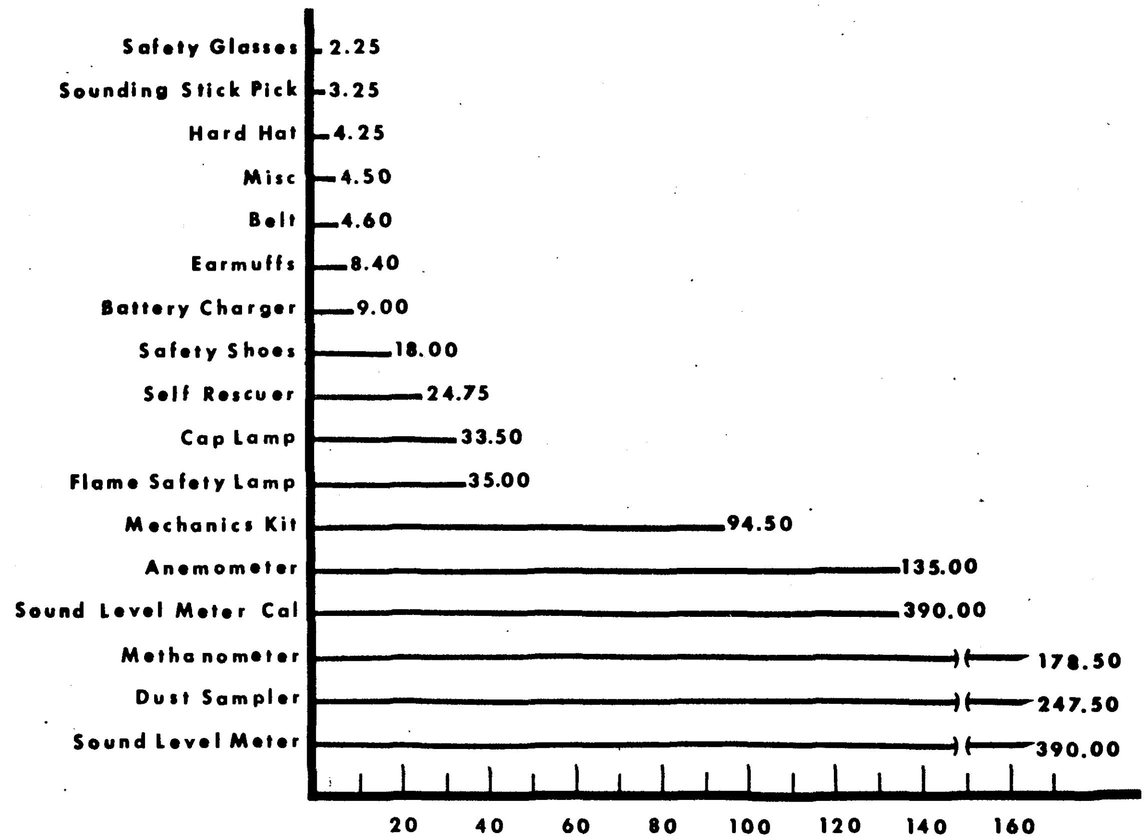

FIGURE 7

OPERATIONAL CALL ALERT/EMERGENCY THROUGH THE EARTH VOICE RECEIVER